

CLAIMS

What is claimed is:

1. A method of patterning redox-active polymers on a surface to form surface-bound redox-active polymers, said method comprising:
 - 5 providing redox-active molecules bearing at least a first reactive site or group and a second reactive site or group; and
 - contacting said surface with said redox-active molecules where said contacting is under conditions that result in attachment of said redox-active molecules to said surface via said first reactive site or group and attachment of redox-active molecules
 - 10 via the second reactive site or group, to the redox-active molecules attached to said surface thereby forming a polymer attached to said surface where said polymers comprise at least two of said redox-active molecules.
2. The method of claim 1, wherein said first reactive site or group and said second reactive site or group are the same species.
- 15 3. The method of claim 1, wherein said first reactive site or group and said second reactive site or group are different species.
4. The method of claim 1, wherein said first reactive site or group and/or said second reactive site or group is attached to said redox-active molecule by a linker.
- 20 5. The method of claim 1, wherein said first reactive site or group is an ethynyl group.
6. The method of claim 5, wherein said second reactive site or group is an ethynyl group.
7. The method of any of claims 5 or 6, wherein said ethynyl group is an
- 25 ethynyl group selected from the group consisting of ethynyl, 4-ethynylphenyl, 3-ethynylphenyl, 4-ethynylbiphenyl, 3-ethynylphenyl, 4-ethynylterphenyl, and 3-ethynylterphenyl.

8. The method of claim 1, wherein said redox-active molecule is selected from the group consisting of a porphyrinic macrocycle, a porphyrin, a sandwich coordination compound of porphyrinic macrocycles, and a metallocene.

9. The method of claim 1, wherein said redox-active molecule is
 5 selected from the group consisting of a linear polyene, a cyclic polyene, a heteroatom-substituted linear polyene, a heteroatom-substituted cyclic polyene, a tetrathiafulvalene, a tetraselenafulvalene, a metal coordination complex, a buckyball, a triarylamine, a 1,4-phenylenediamine, a xanthene, a flavin, a phenazine, a phenothiazine, an acridine, a quinoline, a 2,2'-bipyridyl, a 4,4'-bipyridyl, a tetrathiotetracene, and a peri-bridged
 10 naphthalene dichalcogenide.

10. The method of claim 1, wherein said redox-active molecule is a porphyrin comprising a substituent selected from the group consisting of: aryl, phenyl, cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

11. The method of claim 1, wherein said redox-active molecule is a porphyrin comprising a substituent selected from the group consisting of: 4-methylphenyl, 4-*t*-butylphenyl, 4-trifluoromethylphenyl, pentyl, and H (no substituent).

12. The method of claim 1, wherein said redox-active molecule is a phthalocyanine comprising a substituent selected from the group consisting of aryl, phenyl,
 20 cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

13. The method of claim 1, wherein said redox-active molecule is a phthalocyanine comprising a substituent selected from the group consisting of methyl, *t*-butyl, butoxy, fluoro, and H (no substituent).

14. The method of claim 1, wherein said redox-active molecule is a molecule found in Table 1.

15. The method of claim 1, wherein said contacting comprises contacting said surface with a linker having the formula



wherein

Z^1 is a surface attachment group;

L^1 is a covalent bond or a linker; and

5 Y^1 is a protected or unprotected reactive site or group;

whereby said linker attaches to said surface; and

contacting the attached linker with said redox-active molecules whereby the redox-active molecules couple to each other via said first and/or said second reactive site or group and the redox-active molecules couple to the linker through Y^1 and said first and/or said second
 10 reactive site or group thereby forming a polymer attached to said linker where said polymer comprises at least two of said redox-active molecules.

16. The method of claim 15, wherein Z^1 is a protected or unprotected reactive site or group selected from the group consisting of a carboxylic acid, an alcohol, a thiol, a selenol, a tellurol, a phosphonic acid, a phosphonothioate, an amine, a nitrile, 4-formylphenyl, 4-(bromomethyl)phenyl, 4-vinylphenyl, 4-ethynylphenyl, 4-allylphenyl, 4-[2-(trimethylsilyl)ethynyl]phenyl, 4-[2-(triisopropylsilyl)ethynyl]phenyl, 4-bromophenyl, 4-iodophenyl, 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl, bromo, iodo, formyl, bromomethyl, chloromethyl, ethynyl, vinyl, allyl, 4-(ethynyl)biphen-4'-yl, 4-[2-(triisopropylsilyl)ethynyl]biphen-4'-yl, 3,5-diethynylphenyl, and 2-bromoethyl.

20 17. The method of claim 15, wherein $-L^1-Z^1-$ is selected from the group consisting of 4-carboxyphenyl, carboxymethyl, 2-carboxyethyl, 3-carboxypropyl, 2-(4-carboxyphenyl)ethynyl, 4-(2-(4-carboxyphenyl)ethynyl)phenyl, 4-carboxymethylphenyl, 4-(3-carboxypropyl)phenyl, 4-(2-(4-carboxymethylphenyl)ethynyl)phenyl; 4-hydroxyphenyl, hydroxymethyl, 2-hydroxyethyl, 3-hydroxypropyl, 2-(4-hydroxyphenyl)ethynyl, 4-(2-(4-hydroxyphenyl)ethynyl)phenyl, 4-hydroxymethylphenyl, 4-(2-hydroxyethyl)phenyl, 4-(3-hydroxypropyl)phenyl, 4-(2-(4-hydroxymethylphenyl)ethynyl)phenyl; 4-mercaptophenyl, mercaptomethyl, 2-mercaptoethyl, 3-mercaptopropyl, 2-(4-mercaptophenyl)ethynyl, 4-(2-(4-mercaptophenyl)ethynyl)phenyl, 4-mercaptomethylphenyl, 4-(2-mercaptoethyl)phenyl, 4-(3-mercaptopropyl)phenyl, 4-(2-(4-mercaptomethylphenyl)ethynyl)phenyl; 4-selenylphenyl, selenylmethyl, 2-selenylethyl, 3-selenylpropyl, 2-(4-selenylphenyl)ethynyl,
 25 4-selenylmethylphenyl, 4-(2-selenylethyl)phenyl, 4-(3-selenylpropyl)phenyl, 4-

selenylmethylphenyl, 4-(2-(4-selenylphenyl)ethynyl)phenyl; 4-tellurylphenyl, tellurylmethyl, 2-tellurylethyl, 3-tellurylpropyl, 2-(4-tellurylphenyl)ethynyl, 4-(2-(4-tellurylphenyl)ethynyl)phenyl, 4-tellurylmethylphenyl, 4-(2-tellurylethyl)phenyl, 4-(3-tellurylpropyl)phenyl, 4-(2-(4-tellurylmethylphenyl)ethynyl)phenyl; 4-

5 (dihydroxyphosphoryl)phenyl, (dihydroxyphosphoryl)methyl, 2-(dihydroxyphosphoryl)ethyl, 3-(dihydroxyphosphoryl)propyl, 2-[4-(dihydroxyphosphoryl)phenyl]ethynyl, 4-[2-[4-(dihydroxyphosphoryl)phenyl]ethynyl]phenyl, 4-[(dihydroxyphosphoryl)methyl]phenyl, 4-[2-(dihydroxyphosphoryl)ethyl]phenyl, 4-[2-[4-

10 (dihydroxyphosphoryl)methylphenyl]ethynyl]phenyl; 4-(hydroxy(mercapto)phosphoryl)phenyl, (hydroxy(mercapto)phosphoryl)methyl, 2-(hydroxy(mercapto)phosphoryl)ethyl, 3-(hydroxy(mercapto)phosphoryl)propyl, 2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl]phenyl, 4-

15 [(hydroxy(mercapto)phosphoryl)methyl]phenyl, 4-[2-(hydroxy(mercapto)phosphoryl)ethyl]phenyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)methylphenyl]ethynyl]phenyl; 4-cyanophenyl, cyanomethyl, 2-cyanoethyl, 3-cyanopropyl, 2-(4-cyanophenyl)ethynyl, 4-[2-(4-cyanophenyl)ethynyl]phenyl, 4-(cyanomethyl)phenyl, 4-(2-cyanoethyl)phenyl, 4-[2-[4-

20 (cyanomethyl)phenyl]ethynyl]phenyl; 4-cyanobiphenyl, 4-aminophenyl, aminomethyl, 2-aminoethyl, 3-aminopropyl, 2-(4-aminophenyl)ethynyl, 4-[2-(4-aminophenyl)ethynyl]phenyl, and 4-aminobiphenyl.

18. The method of claim 15, wherein L is selected from the group consisting of a covalent bond, 1,4-phenylene, 4,4'-diphenylethyne, 4,4'-diphenylbutadiyne, 4,4'-biphenyl, 4,4'-stilbene, 1,4-bicyclooctane, 4,4'-azobenzene, 4,4'-benzylideneaniline, and 4,4''-terphenyl.

19. The method of claim 15, wherein said method further comprises attaching a counterelectrode to said polymer.

20. The method of claim 19, wherein said counterelectrode is attached directly to said polymer.

21. The method of claim 19, wherein said counterelectrode is attached to said polymer through a linker.

22. The method of claim 15, wherein said redox-active molecules further comprise redox-active molecules having only one available reactive group or site.

5 23. The method of claim 22, wherein said redox-active molecules having only one available reactive group or site comprise a second reactive group or site that is blocked.

10 24. The method of claim 1, wherein said surface comprises a material selected from the group consisting of a Group III element, a Group IV element, a Group V element, a doped Group III element, a doped Group IV element, a doped Group V element, a transition metal, a transition metal oxide, and a transition metal nitride.

25. The method of claim 24, wherein said surface comprises a material selected from the group consisting of silicon, germanium, doped silicon, and doped germanium.

15 26. The method of claim 24, wherein said surface is a hydrogen passivated surface.

27. A method of patterning redox-active polymers on a surface to form surface-bound redox-active polymers, said method comprising:
providing a surface having attached thereto a linker bearing a reactive
20 site or group and/or a redox-active molecule bearing a reactive site or group;
providing redox-active molecules bearing at least a first reactive site or group and a second reactive site or group; and
contacting said surface with said redox-active molecules where said
contacting is under conditions that result in the attachment of said redox-active molecules to
25 the linker and/or to the redox-active molecule attached to the surface and the polymerization of the redox-active molecules thereby forming polymers attached to said surface where said polymers comprise at least two of said redox-active molecules.

28. The method of claim 27, wherein said first reactive site or group and said second reactive site or group are the same species.

29. The method of claim 27, wherein said first reactive site or group and said second reactive site or group are different species.

5 30. The method of claim 27, wherein said first reactive site or group and/or said second reactive site or group is attached to said redox-active molecule by a linker.

31. The method of claim 27, wherein said first reactive site or group is an ethynyl group.

10 32. The method of claim 31, wherein said second reactive site or group is an ethynyl group.

33. The method of any of claims 31 or 32, wherein said ethynyl group is an ethynyl group selected from the group consisting of ethynyl, 4-ethynylphenyl, 3-ethynylphenyl, 4-ethynylbiphenyl, 3-ethynylphenyl, 4-ethynylterphenyl, and 3-ethynylterbiphenyl.

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34. The method of claim 27, wherein said redox-active molecule is selected from the group consisting of a porphyrinic macrocycle, a porphyrin, a sandwich coordination compound of porphyrinic macrocycles, and a metallocene.

35. The method of claim 27, wherein said redox-active molecule is selected from the group consisting of a linear polyene, a cyclic polyene, a heteroatom-substituted linear polyene, a heteroatom-substituted cyclic polyene, a tetrathiafulvalene, a tetraselenafulvalene, a metal coordination complex, a buckyball, a triarylamine, a 1,4-phenylenediamine, a xanthene, a flavin, a phenazine, a phenothiazine, an acridine, a quinoline, a 2,2'-bipyridyl, a 4,4'-bipyridyl, a tetrathiotetracene, and a peri-bridged naphthalene dichalcogenide.

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36. The method of claim 27, wherein said redox-active molecule is a porphyrin comprising a substituent selected from the group consisting of: aryl, phenyl,

cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

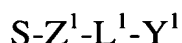
37. The method of claim 27, wherein said redox-active molecule is a porphyrin comprising a substituent selected from the group consisting of: 4-methylphenyl, 4-*t*-butylphenyl, 4-trifluoromethylphenyl, pentyl, and H (no substituent).

38. The method of claim 27, wherein said redox-active molecule is a phthalocyanine comprising a substituent selected from the group consisting of aryl, phenyl, cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

39. The method of claim 27, wherein said redox-active molecule is a phthalocyanine comprising a substituent selected from the group consisting of methyl, *t*-butyl, butoxy, fluoro, and H (no substituent).

40. The method of claim 27, wherein said redox-active molecule is a molecule found in Table 1.

41. The method of claim 27, wherein said providing comprises providing a surface having attached thereto a linker whereby said surface and linker have the formula



wherein

S is the surface;
 Z^1 is a surface attachment group;
 L^1 is a covalent bond or a linker; and
 Y^1 is a protected or unprotected reactive site or group.

42. The method of claim 41, wherein Y^1 is a protected reactive site or group and said method further comprises deprotecting Y^1 .

43. The method of claim 41, wherein Z^1 , before coupling to said surface, is a protected or unprotected reactive site or group selected from the group consisting of a carboxylic acid, an alcohol, a thiol, a selenol, a tellurol, a phosphonic acid, a phosphonothioate, an amine, a nitrile, 4-formylphenyl, 4-(bromomethyl)phenyl, 4-

vinylphenyl, 4-ethynylphenyl, 4-allylphenyl, 4-[2-(trimethylsilyl)ethynyl]phenyl, 4-[2-(triisopropylsilyl)ethynyl]phenyl, 4-bromophenyl, 4-iodophenyl, 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl, bromo, iodo, formyl, bromomethyl, chloromethyl, ethynyl, vinyl, allyl, 4-(ethynyl)biphen-4'-yl, 4-[2-(triisopropylsilyl)ethynyl]biphen-4'-yl, 3,5-
 5 diethynylphenyl, and 2-bromoethyl.

44. The method of claim 41, wherein Z^1-L^1 , before coupling to said surface, is selected from the group consisting of 4-carboxyphenyl, carboxymethyl, 2-carboxyethyl, 3-carboxypropyl, 2-(4-carboxyphenyl)ethynyl, 4-(2-(4-carboxyphenyl)ethynyl)phenyl, 4-carboxymethylphenyl, 4-(3-carboxypropyl)phenyl, 4-(2-(4-carboxymethylphenyl)ethynyl)phenyl; 4-hydroxyphenyl, hydroxymethyl, 2-hydroxyethyl, 3-hydroxypropyl, 2-(4-hydroxyphenyl)ethynyl, 4-(2-(4-hydroxyphenyl)ethynyl)phenyl, 4-hydroxymethylphenyl, 4-(2-hydroxyethyl)phenyl, 4-(3-hydroxypropyl)phenyl, 4-(2-(4-hydroxymethylphenyl)ethynyl)phenyl; 4-mercaptophenyl, mercaptomethyl, 2-mercaptoethyl, 3-mercaptopropyl, 2-(4-mercaptophenyl)ethynyl, 4-(2-(4-mercaptophenyl)ethynyl)phenyl, 4-mercaptomethylphenyl, 4-(2-mercaptoethyl)phenyl, 4-(3-mercaptopropyl)phenyl, 4-(2-(4-mercaptomethylphenyl)ethynyl)phenyl; 4-selenylphenyl, selenylmethyl, 2-selenylethyl, 3-selenylpropyl, 2-(4-selenylphenyl)ethynyl, 4-selenylmethylphenyl, 4-(2-selenylethyl)phenyl, 4-(3-selenylpropyl)phenyl, 4-selenylmethylphenyl, 4-(2-(4-selenylphenyl)ethynyl)phenyl; 4-tellurylphenyl, tellurylmethyl, 2-tellurylethyl, 3-tellurylpropyl, 2-(4-tellurylphenyl)ethynyl, 4-(2-(4-tellurylphenyl)ethynyl)phenyl, 4-tellurylmethylphenyl, 4-(2-tellurylethyl)phenyl, 4-(3-tellurylpropyl)phenyl, 4-(2-(4-tellurylmethylphenyl)ethynyl)phenyl; 4-(dihydroxyphosphoryl)phenyl, (dihydroxyphosphoryl)methyl, 2-(dihydroxyphosphoryl)ethyl, 3-(dihydroxyphosphoryl)propyl, 2-[4-(dihydroxyphosphoryl)phenyl]ethynyl, 4-[2-[4-(dihydroxyphosphoryl)phenyl]ethynyl]phenyl, 4-[(dihydroxyphosphoryl)methyl]phenyl, 4-[2-(dihydroxyphosphoryl)ethyl]phenyl, 4-[2-[4-(dihydroxyphosphoryl)methylphenyl]ethynyl]phenyl; 4-(hydroxy(mercapto)phosphoryl)phenyl, (hydroxy(mercapto)phosphoryl)methyl, 2-(hydroxy(mercapto)phosphoryl)ethyl, 3-(hydroxy(mercapto)phosphoryl)propyl, 2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl]phenyl, 4-

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[(hydroxy(mercapto)phosphoryl)methyl]phenyl, 4-[2-(hydroxy(mercapto)phosphoryl)ethyl]phenyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)methylphenyl]ethynyl]phenyl; 4-cyanophenyl, cyanomethyl, 2-cyanoethyl, 3-cyanopropyl, 2-(4-cyanophenyl)ethynyl, 4-[2-(4-cyanophenyl)ethynyl]phenyl, 4-(cyanomethyl)phenyl, 4-(2-cyanoethyl)phenyl, 4-[2-[4-(cyanomethyl)phenyl]ethynyl]phenyl; 4-cyanobiphenyl, 4-aminophenyl, aminomethyl, 2-aminoethyl, 3-aminopropyl, 2-(4-aminophenyl)ethynyl, 4-[2-(4-aminophenyl)ethynyl]phenyl, and 4-aminobiphenyl.

45. The method of claim 41, wherein L^1 is selected from the group consisting of a covalent bond, 1,4-phenylene, 4,4'-diphenylethyne, 4,4'-diphenylbutadiyne, 4,4'-biphenyl, 4,4'-stilbene, 1,4-bicyclooctane, 4,4'-azobenzene, 4,4'-benzylideneaniline, and 4,4''-terphenyl.

46. The method of claim 27, wherein said method further comprises attaching a counterelectrode to said polymer.

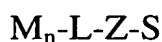
47. The method of claim 46, wherein said counterelectrode is attached directly to said polymer.

48. The method of claim 46, wherein said counterelectrode is attached to said polymer through a linker.

49. The method of claim 27, wherein said redox-active molecules further comprise redox-active molecules having only one available reactive group or site.

50. The method of claim 49, wherein said redox-active molecules having only one available reactive group or site comprise a second reactive group or site that is blocked.

51. An electroactive substrate comprising a first zone wherein said first zone comprises a surface with an attached redox-active moiety according to the formula:



wherein:

S is a substrate;
 Z is a surface attachment group;
 L is a linker or covalent bond;
 M is a redox-active molecule; and
 n is at least 3.

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52. The electroactive substrate of claim 51, wherein the redox-active molecules are attached to each other through an ethynyl group.

53. The electroactive substrate of claim 52, wherein said ethynyl group is an ethynyl group selected from the group consisting of ethynyl, 4-ethynylphenyl, 3-ethynylphenyl, 4-ethynylbiphenyl, 3-ethynylphenyl, 4-ethynylterphenyl, and 3-ethynylterphenyl.

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54. The electroactive substrate of claim 51, wherein said redox-active molecules are selected from the group consisting of a porphyrinic macrocycle, a porphyrin, a sandwich coordination compound of porphyrinic macrocycles, and a metallocene.

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55. The electroactive substrate of claim 51, wherein said redox-active molecules are selected from the group consisting of a linear polyene, a cyclic polyene, a heteroatom-substituted linear polyene, a heteroatom-substituted cyclic polyene, a tetrathiafulvalene, a tetraselenafulvalene, a metal coordination complex, a buckyball, a triarylamine, a 1,4-phenylenediamine, a xanthene, a flavin, a phenazine, a phenothiazine, an acridine, a quinoline, a 2,2'-bipyridyl, a 4,4'-bipyridyl, a tetrathiotetracene, and a peri-bridged naphthalene dichalcogenide.

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56. The electroactive substrate of claim 51, wherein said redox-active molecules are porphyrins comprising a substituent selected from the group consisting of: aryl, phenyl, cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

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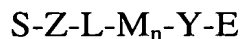
57. The electroactive substrate of claim 51, wherein said redox-active molecules are porphyrins comprising a substituent selected from the group consisting of: 4-methylphenyl, 4-*t*-butylphenyl, 4-trifluoromethylphenyl, pentyl, and H (no substituent).

58. The electroactive substrate of claim 51, wherein said redox-active molecules are phthalocyanines comprising a substituent selected from the group consisting of aryl, phenyl, cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

59. The electroactive substrate of claim 51, wherein said redox-active molecules are phthalocyanines comprising a substituent selected from the group consisting of methyl, *t*-butyl, butoxy, fluoro, and H (no substituent).

60. The electroactive substrate of claim 51, wherein said redox-active molecules comprise a molecule found in Table 1.

61. The electroactive substrate of claim 51, wherein said substrate comprises a surface with an attached redox-active moiety according to the formula:



wherein

15 Y is a linker or a reactive site or group; and
E is a counterelectrode.

62. The electroactive substrate of claim 51, wherein Z, before coupling to said surface, is a protected or unprotected reactive site or group selected from the group consisting of a carboxylic acid, an alcohol, a thiol, a selenol, a tellurol, a phosphonic acid, a phosphonothioate, an amine, a nitrile, 4-formylphenyl, 4-(bromomethyl)phenyl, 4-vinylphenyl, 4-ethynylphenyl, 4-allylphenyl, 4-[2-(trimethylsilyl)ethynyl]phenyl, 4-[2-(triisopropylsilyl)ethynyl]phenyl, 4-bromophenyl, 4-iodophenyl, 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl, bromo, iodo, formyl, bromomethyl, chloromethyl, ethynyl, vinyl, allyl, 4-(ethynyl)biphen-4'-yl, 4-[2-(triisopropylsilyl)ethynyl]biphen-4'-yl, 3,5-diethynylphenyl, and 2-bromoethyl.

63. The electroactive substrate of claim 51, wherein Z-L-, before coupling to said surface, is selected from the group consisting of 4-carboxyphenyl, carboxymethyl, 2-carboxyethyl, 3-carboxypropyl, 2-(4-carboxyphenyl)ethynyl, 4-(2-(4-carboxyphenyl)ethynyl)phenyl, 4-carboxymethylphenyl, 4-(3-carboxypropyl)phenyl, 4-(2-

(4-carboxymethylphenyl)ethynyl)phenyl; 4-hydroxyphenyl, hydroxymethyl, 2-hydroxyethyl, 3-hydroxypropyl, 2-(4-hydroxyphenyl)ethynyl, 4-(2-(4-hydroxyphenyl)ethynyl)phenyl, 4-hydroxymethylphenyl, 4-(2-hydroxyethyl)phenyl, 4-(3-hydroxypropyl)phenyl, 4-(2-(4-hydroxymethylphenyl)ethynyl)phenyl; 4-mercaptophenyl, mercaptomethyl, 2-mercaptoethyl, 3-mercaptopropyl, 2-(4-mercaptophenyl)ethynyl, 4-(2-(4-mercaptophenyl)ethynyl)phenyl, 4-mercaptomethylphenyl, 4-(2-mercaptoethyl)phenyl, 4-(3-mercaptopropyl)phenyl, 4-(2-(4-mercaptomethylphenyl)ethynyl)phenyl; 4-selenylphenyl, selenylmethyl, 2-selenylethyl, 3-selenylpropyl, 2-(4-selenylphenyl)ethynyl, 4-selenylmethylphenyl, 4-(2-selenylethyl)phenyl, 4-(3-selenylpropyl)phenyl, 4-selenylmethylphenyl, 4-(2-(4-selenylphenyl)ethynyl)phenyl; 4-tellurylphenyl, tellurylmethyl, 2-tellurylethyl, 3-tellurylpropyl, 2-(4-tellurylphenyl)ethynyl, 4-(2-(4-tellurylphenyl)ethynyl)phenyl, 4-tellurylmethylphenyl, 4-(2-tellurylethyl)phenyl, 4-(3-tellurylpropyl)phenyl, 4-(2-(4-tellurylmethylphenyl)ethynyl)phenyl; 4-(dihydroxyphosphoryl)phenyl, (dihydroxyphosphoryl)methyl, 2-(dihydroxyphosphoryl)ethyl, 3-(dihydroxyphosphoryl)propyl, 2-[4-(dihydroxyphosphoryl)phenyl]ethynyl, 4-[2-[4-(dihydroxyphosphoryl)phenyl]ethynyl]phenyl, 4-[(dihydroxyphosphoryl)methyl]phenyl, 4-[2-(dihydroxyphosphoryl)ethyl]phenyl, 4-[2-[4-(dihydroxyphosphoryl)methylphenyl]ethynyl]phenyl; 4-(hydroxy(mercapto)phosphoryl)phenyl, (hydroxy(mercapto)phosphoryl)methyl, 2-(hydroxy(mercapto)phosphoryl)ethyl, 3-(hydroxy(mercapto)phosphoryl)propyl, 2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl]phenyl, 4-[(hydroxy(mercapto)phosphoryl)methyl]phenyl, 4-[2-(hydroxy(mercapto)phosphoryl)ethyl]phenyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)methylphenyl]ethynyl]phenyl; 4-cyanophenyl, cyanomethyl, 2-cyanoethyl, 3-cyanopropyl, 2-(4-cyanophenyl)ethynyl, 4-[2-(4-cyanophenyl)ethynyl]phenyl, 4-(cyanomethyl)phenyl, 4-(2-cyanoethyl)phenyl, 4-[2-[4-(cyanomethyl)phenyl]ethynyl]phenyl; 4-cyanobiphenyl, 4-aminophenyl, aminomethyl, 2-aminoethyl, 3-aminopropyl, 2-(4-aminophenyl)ethynyl, 4-[2-(4-aminophenyl)ethynyl]phenyl, and 4-aminobiphenyl.

64. The electroactive substrate of claim 51, wherein L is selected from the group consisting of a covalent bond, 1,4-phenylene, 4,4'-diphenylethyne, 4,4'-diphenylbutadiyne, 4,4'-biphenyl, 4,4'-stilbene, 1,4-bicyclooctane, 4,4'-azobenzene, 4,4'-benzylideneaniline, and 4,4''-terphenyl.

5 65. The electroactive substrate of claim 51, further comprising a second zone wherein said second zone comprises a surface with an attached redox-active moiety wherein said redox-active moiety is different than M.

66. The electroactive substrate of claim 51, wherein said first zone is a redox-active storage cell.

10 67. A redox-active storage cell, said storage cell comprising a surface with an attached redox-active moiety according to the formula:



wherein:

15 S is a substrate;
Z is a surface attachment group;
L is a linker linkers or covalent bond;
M is a redox-active molecule;
Y is a reactive site or group or a linker;
E is a counter-electrode; and
20 n is at least 3.

68. The redox-active storage cell of claim 67, wherein the redox-active molecules are attached to each other through an ethynyl group.

69. The electroactive substrate of claim 68, wherein said ethynyl group is an ethynyl group selected from the group consisting of ethynyl, 4-ethynylphenyl, 3-ethynylphenyl, 4-ethynylbiphenyl, 3-ethynylphenyl, 4-ethynylterphenyl, and 3-ethynylterphenyl.

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70. The redox-active storage cell of claim 67, wherein said redox-active molecules are selected from the group consisting of a porphyrinic macrocycle, a porphyrin, a sandwich coordination compound of porphyrinic macrocycles, and a metallocene.

71. The redox-active storage cell of claim 67, wherein said redox-active molecules are selected from the group consisting of a linear polyene, a cyclic polyene, a heteroatom-substituted linear polyene, a heteroatom-substituted cyclic polyene, a tetrathiafulvalene, a tetraselenafulvalene, a metal coordination complex, a buckyball, a triarylamine, a 1,4-phenylenediamine, a xanthene, a flavin, a phenazine, a phenothiazine, an acridine, a quinoline, a 2,2'-bipyridyl, a 4,4'-bipyridyl, a tetrathiotetracene, and a peri-bridged naphthalene dichalcogenide.

72. The redox-active storage cell of claim 67, wherein said redox-active molecules are porphyrins comprising a substituent selected from the group consisting of: aryl, phenyl, cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

73. The redox-active storage cell of claim 67, wherein said redox-active molecules are porphyrins comprising a substituent selected from the group consisting of: 4-methylphenyl, 4-*t*-butylphenyl, 4-trifluoromethylphenyl, pentyl, and H (no substituent).

74. The redox-active storage cell of claim 67, wherein said redox-active molecules are phthalocyanines comprising a substituent selected from the group consisting of aryl, phenyl, cycloalkyl, alkyl, halogen, alkoxy, alkylthio, perfluoroalkyl, perfluoroaryl, pyridyl, cyano, thiocyanato, nitro, amino, alkylamino, acyl, sulfoxyl, sulfonyl, amido, and carbamoyl.

75. The redox-active storage cell of claim 67, wherein said redox-active molecules are phthalocyanines comprising a substituent selected from the group consisting of methyl, *t*-butyl, butoxy, fluoro, and H (no substituent).

76. The redox-active storage cell of claim 67, wherein said redox-active molecules comprise a molecule found in Table 11.

77. The redox-active storage cell of claim 67, wherein Z, before coupling to said surface, is a protected or unprotected reactive site or group selected from the group consisting of a carboxylic acid, an alcohol, a thiol, a selenol, a tellurol, a phosphonic acid, a phosphonothioate, an amine, a nitrile, 4-formylphenyl, 4-(bromomethyl)phenyl, 4-vinylphenyl, 4-ethynylphenyl, 4-allylphenyl, 4-[2-(trimethylsilyl)ethynyl]phenyl, 4-[2-(triisopropylsilyl)ethynyl]phenyl, 4-bromophenyl, 4-iodophenyl, 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl, bromo, iodo, formyl, bromomethyl, chloromethyl, ethynyl, vinyl, allyl, 4-(ethynyl)biphen-4'-yl, 4-[2-(triisopropylsilyl)ethynyl]biphen-4'-yl, 3,5-diethynylphenyl, and 2-bromoethyl.

78. The redox-active storage cell of claim 67, wherein -L-Z-, before coupling to said surface, is selected from the group consisting of 4-carboxyphenyl, carboxymethyl, 2-carboxyethyl, 3-carboxypropyl, 2-(4-carboxyphenyl)ethynyl, 4-(2-(4-carboxyphenyl)ethynyl)phenyl, 4-carboxymethylphenyl, 4-(3-carboxypropyl)phenyl, 4-(2-(4-carboxymethylphenyl)ethynyl)phenyl; 4-hydroxyphenyl, hydroxymethyl, 2-hydroxyethyl, 3-hydroxypropyl, 2-(4-hydroxyphenyl)ethynyl, 4-(2-(4-hydroxyphenyl)ethynyl)phenyl, 4-hydroxymethylphenyl, 4-(2-hydroxyethyl)phenyl, 4-(3-hydroxypropyl)phenyl, 4-(2-(4-hydroxymethylphenyl)ethynyl)phenyl; 4-mercaptophenyl, mercaptomethyl, 2-mercaptoethyl, 3-mercaptopropyl, 2-(4-mercaptophenyl)ethynyl, 4-(2-(4-mercaptophenyl)ethynyl)phenyl, 4-mercaptomethylphenyl, 4-(2-mercaptoethyl)phenyl, 4-(3-mercaptopropyl)phenyl, 4-(2-(4-mercaptomethylphenyl)ethynyl)phenyl; 4-selenylphenyl, selenylmethyl, 2-selenylethyl, 3-selenylpropyl, 2-(4-selenylphenyl)ethynyl, 4-selenylmethylphenyl, 4-(2-selenylethyl)phenyl, 4-(3-selenylpropyl)phenyl, 4-selenylmethylphenyl, 4-(2-(4-selenylphenyl)ethynyl)phenyl; 4-tellurylphenyl, tellurylmethyl, 2-tellurylethyl, 3-tellurylpropyl, 2-(4-tellurylphenyl)ethynyl, 4-(2-(4-tellurylphenyl)ethynyl)phenyl, 4-tellurylmethylphenyl, 4-(2-tellurylethyl)phenyl, 4-(3-tellurylpropyl)phenyl, 4-(2-(4-tellurylmethylphenyl)ethynyl)phenyl; 4-(dihydroxyphosphoryl)phenyl, (dihydroxyphosphoryl)methyl, 2-(dihydroxyphosphoryl)ethyl, 3-(dihydroxyphosphoryl)propyl, 2-[4-(dihydroxyphosphoryl)phenyl]ethynyl, 4-[2-[4-(dihydroxyphosphoryl)phenyl]ethynyl]phenyl, 4-[(dihydroxyphosphoryl)methyl]phenyl, 4-[2-(dihydroxyphosphoryl)ethyl]phenyl, 4-[2-[4-(dihydroxyphosphoryl)methylphenyl]ethynyl]phenyl; 4-

(hydroxy(mercapto)phosphoryl)phenyl, (hydroxy(mercapto)phosphoryl)methyl, 2-(hydroxy(mercapto)phosphoryl)ethyl, 3-(hydroxy(mercapto)phosphoryl)propyl, 2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)phenyl]ethynyl]phenyl, 4-
 5 [(hydroxy(mercapto)phosphoryl)methyl]phenyl, 4-[2-(hydroxy(mercapto)phosphoryl)ethyl]phenyl, 4-[2-[4-(hydroxy(mercapto)phosphoryl)methylphenyl]ethynyl]phenyl; 4-cyanophenyl, cyanomethyl, 2-cyanoethyl, 3-cyanopropyl, 2-(4-cyanophenyl)ethynyl, 4-[2-(4-cyanophenyl)ethynyl]phenyl, 4-(cyanomethyl)phenyl, 4-(2-cyanoethyl)phenyl, 4-[2-[4-(cyanomethyl)phenyl]ethynyl]phenyl; 4-cyanobiphenyl, 4-aminophenyl, aminomethyl, 2-aminoethyl, 3-aminopropyl, 2-(4-aminophenyl)ethynyl, 4-[2-(4-aminophenyl)ethynyl]phenyl, and 4-aminobiphenyl.

79. The redox-active storage cell of claim 67, wherein L is selected from the group consisting of a covalent bond, 1,4-phenylene, 4,4'-diphenylethyne, 4,4'-
 15 diphenylbutadiyne, 4,4'-biphenyl, 4,4'-stilbene, 1,4-bicyclooctane, 4,4'-azobenzene, 4,4'-benzylideneaniline, and 4,4''-terphenyl.

80. The redox-active storage cell of claim 67, wherein said counter-electrode comprises a conductive material.

81. The redox-active storage cell of claim 67, wherein said counter-
 20 electrode comprises a semiconductive material.

82. The redox-active storage cell of claim 67, wherein said storage cell is encapsulated.

83. A method of storing data, said method comprising:
 i) providing an apparatus comprising one or more storage cells
 25 according to claim 67; and
 ii) applying a voltage to said counter-electrode at sufficient current to set an oxidation state of M_n .

84. The method of claim 83, wherein said voltage ranges up to about 2 volts.

85. The method of claim 83, wherein said voltage is the output of an integrated circuit.

86. The method of claim 83, wherein said voltage is the output of a logic gate.

5 87. The method of claim 83, further comprising detecting the oxidation state of M_n and thereby reading out the data stored therein.

88. The method of claim 87, wherein said detecting the oxidation state of M_n further comprises refreshing the oxidation state of M_n .

10 89. The method of claim 87, wherein said detecting comprises analyzing a readout signal in the time domain.

90. The method of claim 87, wherein said detecting comprises analyzing a readout signal in the frequency domain.

91. The method of claim 87, wherein said detecting comprises performing a Fourier transform on said readout signal.

15 92. The method of claim 87, wherein said detecting utilizes a voltammetric method.

93. The method of claim 87, wherein said detecting utilizes impedance spectroscopy.

20 94. The method of claim 87, wherein said detecting comprises exposing said storage medium to an electric field to produce an electric field oscillation having characteristic frequency and detecting said characteristic frequency.

95. The method of claim 87, wherein M_n has at least eight different and distinguishable oxidation states.

25 96. In a computer system, a memory device, said memory device comprising a storage cell according to claim 67; an.

97. A computer system comprising a central processing unit, a display, a selector device, and a memory device, said memory device comprising a storage cell according to claim 67.